POLLUTION, FISH MORTALITY & ENVIRONMENTAL PARAMETERS IN LAKE NAINITAL[1]

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Indepth studies on pollution, fish mortality and waterborne human disease have revealed severe pollution in the entrophied Himalayan lake Nainital, India, as evidenced by physico-chemical and biological indicators. The hazardous effect on fish life has been evidenced by mass fish mortality every winter and decimation of fish population of the lake (mainly Mahseer, *Tor tor, T. putitora;* the common carp, *Cyprinus carpio;* the Himalayan trout *Schizothorax richardsoni* and the forage fish, *Puntius* species — *conchonius, sophore* and *ticto*).

Metallic pollution of the lake is high, as estimated by atomic absorption spectrophotometry. Bacteriological studies have also revealed contamination by *Escherichia coli* and other coliforms; causing human diseases in Nainital, as confirmed by records of Govt. and other hospitals in Nainital and Weibel *et al.* (1964).

INTRODUCTION

Lake Nainital is a huge *cul-de-sac,* situated at an altitude of 1938 m, asl, (29° 24′ N, 79° 23′E). It is a beanshaped lake divisible into a large Mallital and small Tallital basins. The lake is 1433 metres long and 463 metres broad, the depth ranging from 6 to 24 metres. Its area is about 48.78 hectares, and the lake capacity (volume when full) 10,772,236/000 Cu M. It is an eutrophic lake moving towards dystrophic condition.

In India, recent studies on aquatic pollution are by David (1959), Ray (1968), Jhingran (1970), Lohani (1970), Saxena *et al.* (1972), Rana & Kumar (1974), Verma and Dalela (1975), Hussaini (1976) and Agrawal & Raj (1978). However, no scientific investigation into the nature, extent and effects of pollution on fishes, lake life and man, have been carried out in the past for Himalayan lakes except for Dal lake (Das 1967a, 1969, 1970, 1971, 1973; Zutshi & Vass 1978), and lake Nainital (Das 1978, Das & Pande 1978, Das & Khanka 1979, Das & Upadyaya 1979).

In the present investigation some of the physical, chemical and biological factors affecting fish and man have been studied in lake Nainital.

MATERIAL AND METHODS

Detection of pollution was done by five methods:

(a) Physical — colour, odour, temperature and turbidity;

(a) Chemical — pH, O_2, CO_2, alkalinity, PO_4-P, NO_3- N, NH_3- N, BOD and DOM;

(c) Biological — High population of pollution indicators and fish mortality;

(d) Quantitative analysis of metal pollution by atomic absorption spectrophotometer;

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(e) Estimation of bacterial pollution by assessing Coliforms and *E. coli*.

The physico-chemical parameters were estimated according to the standard methods given by ISI (1963), WHO (1975), FAO (1967), APHA (AWWA) (1975), Golterman (1969) and Schwoerbel (1970).

The biological indicators of pollution were estimated according to the methods of Kolkwitz (1950), Bick (1963), Sladecek (1963), Hynes (1966), Kolkwitz & Marson (1967), Hart & Fuller (1974) and McCaull & Crossland (1974).

One thousand dead fishes were collected in December & January by random sampling after fish-kill, which were identified as adult *Puntius* (3 species), *Cyprinus carpio* juveniles and *Schizothorax richardsoni* adult and juveniles.

Some Nainital data have been compared with those of oligotrophic lake Bhimtal (Tables I and II), in order to show the contrast between the eutrophic and the oligotrophic lakes. Similarly, the results have been compared with eutrophic polluted lakes in Western countries.

Observations and Results

Polluting matter is brought into Nainital lake through 24 inlet channels observed around the lake. Fifteen of them are seasonal and carry mainly erosion silt and minerals into the lake in the rainy season (July to September); while the other 9 are permanent municipal nallahs or channels which bring highly polluted water from the Nainital town and the lake environs. The effluents falling into the lake contain domestic wastes, general garbage, organic matter, detergents, chemicals from the laboratories around the lake, and also some sewage from the densely populated parts of the town.

Physico-chemical Parameters:

The ranges of physical parameters of Nainital (for the year 1978-79) are as follows:

Temperature varied from 10.5°C (January) to 25.0°C (June); colour changed from brownish green (January-February) to dark green (May-June), yellowish green (July, August, September), and finally bluish green

Table I

Percentage occurrence of main groups of Zooplankton (1978-79)

	Nainital			Bhimtal		
Months	Rotifers	Copepods	Cladocerans	Rotifers	Copepods	Cladocerans
1978						
October	4.98	92.00	2.00	1.32	60.00	26.00
November	7.90	91.00	0.80	12.00	58.00	19.00
December	1.10	98.00	0.50	0.80	60.00	15.00
1979						
January	Rare	100.00	Rare	Rare	56.00	25.00
February	Rare	100.00	Rare	Rare	74.00	24.00
March	61.00	38.00	Rare	9.00	73.00	14.00
April	40.00	59.00	Rare	3.00	24.00	8.00

(November), while December-January it is brownish green to rust colour. The odour varied from strong methane (May) to fishy and H_2S (November, December, January); Turbidity (Secchi) recorded as 100 cm (August) to 178 cm (December); pH ranged from 6.8 (January) to 8.9 (July-August).

In the chemical parameters, DO ranged from 0.8 mg/l (December) to 12.3 mg/l (May); CO_2 from zero (during six warm months) to 18.6 mg/l (December-January); alkalinity from 270 mg/l (June) to 330 mg/l (February); PO_4-P from 0.02 mg/l (March) to 0.05 mg/l (June); No_3-N from 0.12 mg/l (July) to 0.64 mg/l (April); NH_4-N 0.017 mg/l (July) to 0.52 mg/l (December); Cl from 26.5 ppm (July) to 35.5 ppm (January); DOM from 26.5 ppm (March) to 55.5 ppm (January); BOM (bottom organic matter) 60 mg/g (August) to 190 mg/g (January), which forms a thick organic mat throughout the year. It is evident from the parameters that most of the values, hazardous to lake life including fishes, lie in December-January, the two months when severe fish mortality was found to occur.

If we compare these physico-chemical parameters of lake Nainital with those of lake Bhimtal, the contrast in lake status becomes evident. Bhimtal turbidity (Secchi) ranges from 385-500 cms. when compared with 100 to 178 cms. of lake Nainital. DO values are also high throughout the year, being 8.1 mg/l to 13.6 mg/l; CO_2 nil to 4.0 mg/l only; pH 7.7 to 8.6; alkalinity low (26.6 to 56.7 ppm); whereas NH_4-N even in the winter is nil. Of special significance is the near absence of BOM in lake Bhimtal, while in Nainital, there is a thick organic bottom mat. All these data show that Bhimtal is oligotrophic but Nainital is eutrophic and polluted.

Metallic environmental pollution is a significant factor in lake Nainital (Table IV). The high values of manganese, lead, zinc, potassium and calcium, specially in the sediments, are environmental factors detrimental to fish.

A. *Zooplankton and Pedon*:

These have been recorded by Das (op. cit.),

TABLE II

PERCENTAGE OCCURRENCE PEDON

Months	Nainital %				Bhimtal %				
	Tubificids	Leeches	Chironomids	Molluscs	Larvae May fly	Aq. Insects	Cladocera	Crab	Molluscs
1978									
May	22	5.0	50	15	25	15	10	2	2
June	25	3.5	55	15	30	25	20	3	2
July	13	5.0	13	4	40	15	30	5	3
August	40	6.0	30	5	20	15	10	2	3
September	20	5.0	50	2	30	10	20	2	1
October	15	5.0	30	6	10	10	30	2	12
November	20	1.5	30	5	Rare	15	50	3	5
December	15	0.5	25	17	Rare	30	40	5	5
1979									
January	10	1.5	70	10	7	10	40	2	5
February	12	2.0	70	15	6	10	54	3	6

Das & Pande (op. cit.) and Das & Upadhyaya (op. cit.), which exhibit many biological indicators of pollution thriving in the lake, some of which are present during November-December along with *Anacystis* bloom. Much of the plankton dies off during December-January, when only Chironomids and molluscs remain in numbers (Table II). The quantitative percentage composition of zooplankton also suffers, since, except for Cyclops swarms, only a few species of copepods remain in moderate numbers during winter. The rotifers and cladocerans are also decimated (Table I).

For example, the chief zooplanktons recorded by the authors on January 9, 1979 (along with fish-kill) were *Euglena, Bursgria* (Protozoa); *Philodina, Rotifer, Colurus* (Rotifera); *Cyclops, Simocephalus, Diaptomus* (Crustacea); *Chironomus, Forcipomyia* (Insecta); *Rhabdolaimus, Dorilaimus* (Nematoda).

The percentage occurrence of Pedon (Table II) also shows radical differences between Nainital and Bhimtal, the former having higher percentage of Chironomids (pollution) and the latter higher cladocera (oligotrophic).

B. *Phytoplankton and Algae*:

Das & Upadhyaya (op. cit.) recorded dominance of blue greens (Cyanophyceae) during autumn, when *Anacystis* was in bloom. But during winter fish-kill most *Anacystis* died and only *Chroococcus* was abundant. These also died at December end and early January, forming a soupy mass along with other dead plankton. The scant algae left were the rope-like *Rhizoclonium, Ulothrix, Spirogyra* and remnants of *Anacystis* and *Chroococcus*.

The diatoms were represented by moderate population of *Scenedesmus, Cymbella* and *Synedra* (pollution indicators) along with sparse population of *Nitzchia* and *Meridion*. The spring and summer diatoms were, however, dominated by *Cymbella, Rhoicosphenea, Pinnularia, Synedra, Fragilloria* and *Navicula*, The phytoplankton population in Nainital lake was at its peak in August, with the green algae *Chlamydomonas*, *Clorterium* and *Endorina* as dominant phytoplanktons (60%). But another peak was observed in October, when 82% of the phytoplanktons consisted of *Microcystis*, (*Anacystis*) and *Anabaena*. The *Microcystis* bloomed in autumn (November) and died in winter (December, January), causing organic water pollution and secretion of toxins that are hazardous to fish. This was succeeded by the micro-plankton bloom of *Chroococcus*, imparting a soupy rust colour to the lake accompanied by high winter fish kill. The summer filamentous algae (*Spirogyra, Oscillatoria, Rhizoclonium* etc.) also underwent death and decay during winter season causing further organic pollution.

C. *Bacterial pollution*:

The coliform bacteria and *E. coli* have been worked out qualitatively and quantitatively for the first time in lake Nainital. These bacteria are not only indicators of sewage pollution but are hazardous to man and animals if they drink the lake water. The constant high counts of coliform and *E. coli* (Table III) signify that there is constant entry of faecal matter into the lake through the many nullahs (since *E. coli* would die within 10-15 days when exposed to air and sun in the open lake). Thus, the high values of *E. coli* signify continuous faecal contamination of the water in the zone of sepsis (Station I). For instance, even outside the zone of sepsis (100 metres away, Station II), the *E. coli* values ranged from 0.05 x 10^1 to 9.70 x 10^4, which is higher than the permissible limits (Prescott 1970; Geldrich 1970).

TABLE III

TOTAL COLIFORMS AND *E. coli* OF NAINITAL LAKE WATER

Months	STATION-I Coliforms MPN/100 ml	STATION-I *E. coli* MPN/100ml	STATION-II Coliforms MPN/100 ml	STATION-II *E. coli* MPN/100 ml
March	6.70×10^4	6.70×10^4	0.22×10^4	0.09×10^4
April	17.00×10^4	13.80×10^4	1.25×10^4	1.22×10^4
May	50.50×10^4	50.50×10^4	0.68×10^4	0.25×10^4
June	12.00×10^4	4.30×10^4	4.60×10^4	4.60×10^4
July	17.25×10^4	13.00×10^4	1.60×10^4	1.00×10^4
August	18.60×10^4	4.69×10^4	15.00×10^4	4.00×10^4
September	21.30×10^4	13.60×10^4	12.70×10^4	9.70×10^4
October	25.50×10^4	22.50×10^4	4.85×10^4	2.17×10^4
November	18.60×10^4	18.60×10^4	0.80×10^4	0.20×10^4
December	14.25×10^4	11.25×10^4	2.50×10^4	0.67×10^4
January	9.20×10^4	4.30×10^4	0.11×10^4	0.05×10^4
February	7.80×10^4	4.10×10^4	0.15×10^4	0.07×10^4

It has been calculated in western countries (McCaull & Crossland (op. cit.) that decomposing organic matter from cities and towns can be calculated at 1 Kg/man/day. Even with a population of 50 thousand around the lake Nainital, this amounts to an input of 50 thousand kilos of DOM and SOM into the lake per day. This means an addition of about 18 million Kgs. of DOM and SOM into the lake per year. Even if a small part of this accumulates without being oxidised at the bottom (forming a BOM mat), the pollution status of the lake becomes self evident and explanatory.

Siltation :

Rapid silting of lake Nainital is another cause of lake pollution and shallowing. Fifty years back, the lake was 29 metres deep at the centre (Neville 1922). Today it is only 24 metres (Das & Khanka 1979). Silt enters the lake through almost all the 24 nullahs but specially from Mallital and North Mall road side, where small peninsulas of debris, rubble and silt project into the lake today. With high siltation the suspensoids (suspended organic matter) get coated round the silt particles and settles down to the bottom, preventing natural oxidation, since DO in bottom water never rises above 5-6 mg/1 and becomes 0.08 mg/l during winter. The bottom water and mud, even in mid-lake, is highly odorous with strong H_2S and Methane odours. This has already been observed in zones of immediate pollution in the lake (Das 1978), and during the present investigations.

Fish mortality :

High Winter fish mortality occurs every winter in lake Nainital, the majority of about 60,000 fishes killed during December 1978 to January 1979, being *Puntius* species. But some *Cyprinus carpio, Schizothorax richardsoni* and their juveniles also died. The once famous Mahaseer (*Tor tor, T. putitora*) are now extinct in lake Nainital, probably due to pollution.

The causes of high winter fish-kill has been found to be depletion of Oxygen in bottom waters, when anaerobic bacteria take over the process of decomposition of BOM, releasing foul smelling H_2S, Methane and Ammonia (Aerobic bacteria evolve only CO_2 when organic matter is decomposed in the presence of oxygen). These gases not only deplete oxygen in water but are toxic, killing most of the plankton, algae and zooplankton in the lake. The dead plankton and SOM clog the gills of the fishes causing asphyxiation. The DO content is reduced to almost zero/mg/l in which no fish or plankton can live.

Fish diseases are common in lake Nainital due to attack of fungi-*Saprolegnia* & *Achlya;* the protozoans *Chilodenella, Costia, Trichodina, Ichthyophthirius,* and *Myxosporidium.* The trematode—*Dacrylogyrus;* the leeches—*Hemiclepsis* and *Glossiphonia;* and the crustacean *Argulus.*

Discussion

The most important factors responsible for eutrophication of fresh water lakes are Phosphorus (PO_4-P) and Nitrogen (NO_3-N) (McCaull & Crossland 1974). Lake Nainital receives about 63% PO_4-P from municipal and urban run-off; consisting of sewage, domestic wastes and detergents; 30% from horse dung, Kitchen garden and minor crop fertilizers; 2% from precipitation; and 4% from surface ground waters in the form of springs. The NO_3-N comes to about 50% from the ground sub-surface water; 20% by precipitation; 10% by municipal and urban run-off; 10% from chemical laboratories and 10% from minor crop and garden fertilizers. It has been calculated (Edmondson 1970) that about 93% P in polluted lakes and over 30% N are due to human activities. The high P and N values in lake Nainital have caused rapid eutrophication and algal blooms of myxophyceae. Excess N may cause Methaemoglobinemia — a health hazard to man, and even injurious to fishes.

Overdose of Nitrogen and Phosphorus, the very nutrients essential for the growth of plankton and aquatic plants, results in high eutrophication, algal blooms and explosion of macrophytes (Landner 1975). Excess PO_4-P comes from detergents and sewage both of which enter lake Nainital in large amounts today. Excess NO_3-N also comes from chemical effluents and aerobic decomposition of organic lake sediments. Excess PO_4-P is also released by breaking up of the iron salts layer at bottom mat (since the hypolimnion is anaerobic) eleven times faster than when O_2 is present (McCaull & Crossland 1974). This appears to be the case also in Nainital where the bottom water (6-24/m) smells strongly of H_2S, indicating anaerobic decomposition of BOM.

It will not be out of place to compare lake Nainital with other polluted lakes in Western countries. Lake Zurich (McCaull & Crossland 1974) has the deep lower basin (50 m) highly polluted, while the shallow upper basin (14 m) remains unpolluted. This pollution of the lower basin started only 50 years back on account of increase of human habitations around the basin, exactly as has happened in lake Nainital during the same period. Fish population in the polluted Zurich basin has become depleted and only coarse fishes are present; while the upper basin still has fine fish.

Lake Lago-da-Orta (Das 1973) is a dead lake today due to copper mining in lake environs and copper poisoning of all lake life. The Nainital lake sediments have accumulated more than 2159 mg/kg. of Lead and 60 mg/kg. of Copper, as in our values (Table IV).

TABLE IV

CONCENTRATION OF HEAVY AND ALKALI EARTH METALS IN LAKE NAINITAL

Metal	Water mg/l		Sediments mg/kg	
	Minimum	Maximum	Minimum	Maximum
Copper	0.0008	0.0155	19.3639	60.6225
Cobalt	0.0079	0.0202	5.5954	12.9892
Lead	0.0202	0.0886	71.3645	268.9156
Manganese	0.1893	1.1951	769.2307	2158.8362
Zinc	Nil	0.0057	49.4151	152.1322
Thalium	0.2105	0.4429	78.5340	149.8814
Lithium	0.0055	0.0087	9.0909	18.2183
Sodium	0.7893	1.1093	21.3333	68.0851
Potassium	95.4545	167.0454	27840.9090	101547.3800
Calcium	37.0857	44.0000	9114.2857	49299.9170

These may cause severe metal poisoning in years to come when the metallic content in water will also become very high and kill off all life.

The Baltic lake (Sea), although deep, is undergoing eutrophication and stagnation, due to excessive nutrient inputs. Similarly lake Erie, Washington and Mandots (USA) are also slowly going dead due to high pollution inputs (McCaull & Crossland 1974). A similar condition has been found in lake Kariba in Africa (Begg 1970).

High eutrophication and pollution can be reversed by reducing/removing/controlling PO_4-P inflow (chiefly detergents as in lake Nainital). But as in lake Erie (McCaull & Corssland 1974), in lake Nainital also (Das 1978), Phosphate has been built up in the lake sediment over decades; and thus from this store of phosphate sufficient nutrient can be released even if future pollution inputs are stopped.

The mass fish mortality sequence in lake Nainital can be summed up as follows :—
Autumn Anacystis bloom ——→ Winter death of most plankton ————→ high DOM and SOM ——→ Depletion of Oxygen in December-January (Winter) ——→ evolution of Ammonia, H_2S & Methane ————→ FISH KILL.

Silt particles form nuclei for accumulation of organic matter (DOM, and SOM) around them. These have been observed to clog the gills of fishes as revealed by microscopical examination and cause asphyxiation. Besides, the decaying *Anacystis* blooms may also produce toxins which are harmful to fish life (Saxena *et al.* 1972, Doudoroff & Katz 1953, Hart and Fuller 1974).

The maximum mortality was of *Puntius ticto, P. sophore, P. conchonius,* as well of juveniles of *Cyprinus carpio* and *Schizothorax richardsoni*. Surprisingly, no juveniles of *Tor tor,* and *T. putitora* were collected during winter fish kill, although about 1000 dead fishes were collected and identified, nor were the adults seen. It, therefore, appears that mahseer (*Tor* spp.) is now extinct from lake Nainital, whereas 25-30 pounders were available even 20 years ago.

It appears that the toxicity of Ammonia and its compounds, as also of H_2S, is strictly correlated with the permeability of the gills (Jones 1962). According to Lagler (1964) a BOD above 3 mg/l, NH_4-N above 0.5 mg/l and DO less than 5 mg/l are fatal to fish. Our average values of BOD 15.6 mg/l, DO 1.40 mg/l and NH_4-N 0.84 mg/l during winter, offers a combination of pollutants in which no fish can live. Our results for lake Nainital conform to the conclusions of Hart (1948), Wallen (1951), Lagler (1964), Arnold (1969), Cairns (1972) and Frost & Collinson (1977) for polluted lakes of Western countries.

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